(51) International Patent Classification[7]: B60C 23/06, B60G 17/015

(21) International Application Number: PCT/EP00/06857

(22) International Filing Date: 18 July 2000 (18.07.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
99114962.6   30 July 1999 (30.07.1999)   EP
60/147,422   6 August 1999 (06.08.1999)   US

(71) Applicant (for all designated States except US): PIRELLI PNEUMATICI S.P.A. [IT/IT]; Viale Sarca, 222, 1-20126 Milano (IT).

(72) Inventors; and
(75) Inventors/Applicants (for US only): CARETTA, Renato [IT/IT]; Viale dei Tigli, 16, 1-21013 Gallarate (IT). CESARINI, Riccardo [IT/IT]; Via Ettore Panseri, 15, 1-24128 Bergamo (IT). MANCOSU, Federico [IT/IT]; Via Antonio Dossi, 6, 1-20135 Milano (IT).

(74) Common Representative: PIRELLI PNEUMATICI S.P.A.; Viale Sarca, 222, 1-20126 Milano (IT).

(81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— With international search report.

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD AND SYSTEM FOR CONTROLLING THE BEHAVIOUR OF A VEHICLE BY CONTROLLING ITS TYRES
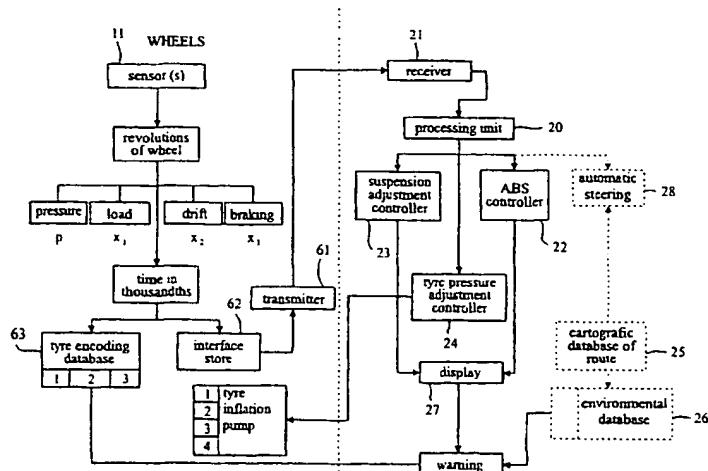
(57) Abstract: The invention relates to a method, a system and a pneumatic wheel for measuring the deformations of the casing of a tyre in operation, for the purpose of taking appropriate corrective action on the vehicle driving and/or control system by comparing the said measured deformations with predetermined values of the deformations. More specifically, the method implements the steps of: measuring the extent of the characteristic deformations of the casing profile of at least one tyre fitted on the vehicle, at a given inflation pressure, comparing the values of these characteristic deformations with stored values representing the behaviour of the tyre in the measured state of deformation, generating a signal for acting on at least one device regulating at least one mechanism for controlling the attitude of the said vehicle in motion, corresponding to the action which has to be taken on the said mechanism to keep the said behaviour of the vehicle within the limits of a predetermined behaviour or to bring it back within these limits.

BEST AVAILABLE COPY

"METHOD AND SYSTEM FOR CONTROLLING THE BEHAVIOUR OF A VEHICLE BY CONTROLLING ITS TYRES"

DESCRIPTION

5

The present invention relates to a method and system for monitoring the operating conditions of a tyre fitted on a vehicle.

10 The present invention relates to the possibility of carrying out actions, whether automatic or actuated or commanded by the driver, on the vehicle driving and/or control system to modify the vehicle's behaviour according to measurements made on the tyre or on the 15 wheel.

Devices for measuring characteristic parameters such as pressure and temperature in a tyre are known from the prior art.

20

Patent application EP 887.211 describes a tyre monitoring system comprising a sensor, located inside the tyre, which is enabled to create an electrical pulse when the said sensor passes through the footprint area formed by 25 the contact of the tyre with the ground during rotation. The system according to this patent also comprises means for measuring the ratio of the duration of the said electrical pulse to the duration of a revolution of the tyre and means for transmitting the said ratio to a 30 processing unit within the vehicle.

In particular, the sensor is located inside the tread of the tyre, in such a way that the said electrical pulse has a first peak at the point where it enters the 35 footprint area and a second peak at the point where it leaves the footprint area.

According to the teaching of this patent, the ratio of the time elapsed between the two peaks to the time taken for a complete revolution of the tyre can be used to discover the degree of flattening of the tyre during the

5 operation of the vehicle.

This is because the sensor detects the instant of entry into the footprint area and the instant of exit from this area. It is thus possible to measure the length of this

10 area, if the angular velocity of the tyre and its radius are known. The length of the footprint area is then related to the flattening of the tyre, which is a critical parameter of the tyre in use, particularly in tyres for heavy motor vehicles.

15

Patent application EP 689.950 describes a different method for monitoring parameters of a tyre, such as its pressure and temperature. In particular, a self-powered programmable electronic device located on the inner

20 surface of a tyre or on its fitting rim is used. This device can be used to monitor and store the pressure, the temperature and the number of rotations of the tyre, and may comprise an extensometer, whose output signal measures the flexion of the inner surface of the tread

25 strip, or an accelerometer which measures the intensity of the acceleration to which the tread strip is subjected. Additionally, the device is activated by an external signal at radio frequencies and transmits an alarm signal if a predetermined limit of the measured

30 values is exceeded.

There are also known methods for measuring deformations of the tread strip of a tyre during movement and transmitting it to a receiver located on the vehicle.

35

Patent application WO 93.25400 describes a sensor located within the tread strip of a tyre and capable of

transmitting a signal directly dependent on the aforesaid deformations, comprising a resonant circuit which oscillates at a predetermined characteristic frequency. This resonant frequency is affected by the deformations of the tread strip during movement, and the sensor transmits electromagnetic waves proportional to these variations of the resonant frequency. These electromagnetic waves are received by a processing unit connected to a receiver located inside the vehicle.

U.S. Patent No. 5,247,831 describes a method for monitoring the behaviour of the footprint area of a tyre during the operation of the vehicle to optimize the driving of the vehicle. In particular, a piezoelectric sensor consisting of longitudinal strips of piezoresistive rubber is inserted into the tread strip. This sensor is capable of measuring the deformations of the tread strip, since these strips change their electrical resistance as a function of the said deformations.

There are also known methods and devices for acting on the vehicle driving and/or control system, particularly on the devices which control the suspension systems of the vehicle, to control its behaviour according to the information obtained from the axles of the vehicle or from the hubs of the wheels.

The publication "A method for the evaluation of the lateral stability of vehicles and tires" by the Società Pneumatici Pirelli S.p.A., presented at the "International Automobile Tire Conference" at Toronto, Canada, on 22 October 1974, illustrates a method of measuring the dynamic behaviour of the vehicle as a function of the forces developed by the various types of tyre set-up and the various conditions of the road surface.

The publication primarily refers to three forces which determine the dynamic behaviour of a tyre, specifically the vertical force, the longitudinal force and the
5   lateral force.

The vertical force is that due to the dynamic load to which the tyre is subjected. The longitudinal force is that due to the torque applied to the axis of the tyre as
10 a result of an acceleration or braking of the vehicle. The lateral force is the resultant of the force due to the characteristic angles of the suspension systems of the vehicle (camber and toe-in) and to the angular thrust (ply-steer) developed by the layers of inclined cords of
15 the ply structure of the tyre, which are also present in normal operating conditions in straight-line motion, and of the thrust generated by the centrifugal force in drifting conditions. The sum of the forces developed by the four tyres generates a resultant system applied to
20 the centre of gravity of the vehicle, which balances the inertial actions and determines the attitude of the vehicle as a function of the characteristics of the suspension systems of each axle. This resultant system is measured by suitable accelerometers, one of which is
25 located on the front axle and one on the rear axle of the vehicle. The article includes a series of graphs showing the centripetal acceleration or the centripetal force applied to the centre of gravity of the vehicle as a function of the angle of skid of the corresponding axle.
30 The graphs plotted for various ground conditions and with various types of tyres can be used to find the behaviour of the vehicle provided with a predetermined tyre set-up and to determine any lateral skidding in either the front or the rear axle in cornering.
35

U.S. Patent No. 5,087,072 illustrates a system of what is called active suspension, consisting of four cylinders,

one being provided for each wheel between the vehicle body and the hub of the wheel. These cylinders are powered by a hydraulic system operated by an electronic control unit. The system comprises a set of sensors for
5 measuring the height of the vehicle above the ground for each suspension unit, and for making this measurement available to the electronic suspension control unit. The control unit operates the active cylinders separately according to the measurement of these heights.

10 The Applicant has observed that the aforesaid known systems of controlling the behaviour of a vehicle are based on systems of forces measured at the hubs of the wheels, and the systems of measuring the deformations of the tyre are based on the measurement of the deformations
15 undergone by the tread strip in the footprint area of the tyre.

The Applicant has observed that the values measured in the cited art cannot be related in a unique way to the
20 operating conditions of a tyre and, more precisely, to the system of forces developed by a tyre in each operating condition.

The present invention arises from the Applicant's
25 realization that the measurement of deformations of the tread strip, particularly in the footprint area of the tyre, can be used to identify the system of forces developed by a tyre and the deformations of the casing of the tyre connected to it and representative of the
30 behaviour of the tyre. This behaviour is of considerable importance, especially during certain special events, such as braking or acceleration of the vehicle, drifting conditions, and variations of load on the tyre.

35 In accordance with the above, the present invention arises from the Applicant's realization that the measurement of the deformations of the casing, since

these are related in a unique way to the system of forces developed by the tyre in use, enables appropriate corrective actions to be taken on the vehicle drive and/or control system by means of the comparison of the
5   said measured deformations with predetermined values thereof.

More specifically, the present invention relates to the control of the behaviour of a vehicle in motion by means
10   of the measurement of characteristic deformations of the tyre during the movement of the vehicle, in such a way as to determine the operating conditions of the tyre by comparison with predetermined values representing the behaviour of the tyre in the various predicted states of
15   deformation. According to the invention, the result of this comparison is used to generate a signal corresponding to a predetermined, preferably automatic, response of one or more devices controlling at least a mechanism for controlling the behaviour, including
20   attitude, of the vehicle in motion, to keep the aforesaid behaviour of the vehicle within the limits of a predetermined behaviour, or to bring it back within these limits.

25   The Applicant has realized that, simply by knowing with certainty the behaviour of each tyre, in other words, the function which relates the force developed by the tyre to its deformation, it is possible to act in the aforementioned way on the control devices of the vehicle
30   in order to modify its behaviour, including attitude, in an optimal way.

It has been found that the measurements of the deformation of the casing structure of the tyre, at a
35   given inflation pressure, in a triad of Cartesian coordinates, in other words, the deformation in the vertical direction, the deformation in the transverse

direction and the deformation in the longitudinal direction, correspond in a unique or at least a reproducible way to the corresponding vertical, lateral and longitudinal forces which act on the tyre (or, in other words, to the forces which the tyre exchanges with the ground).

The Applicant has found that these deformations can be measured from the interior of the tyre independently of the events in the footprint area or, more generally, the interface conditions between the tyre and the ground.

It has also been found that the said predetermined values representing the behaviour of the tyre in the various predicted states of deformation can advantageously be:
- calculated by simulation in a computer,
- measured in the laboratory by means of special test machines which can be used to plot force-deformation graphs in various conditions,
- obtained for each tyre on the vehicle in use or on a simulator apparatus.

In a first aspect, the present invention relates to a method for controlling the movement of a vehicle including at least one wheel provided with a tyre, the said method comprising the steps of:
- determining the deformations of the said tyre by measuring them by means of the reflection of a signal emitted inside the wheel;
- providing a database containing values of deformation of the tyre which correspond to a predetermined behaviour of the wheel;
- comparing the said measured deformations with the said predetermined values of deformation; and
- emitting a signal dependent on the result of the said comparison, to be used for controlling the behaviour of the vehicle.

In particular, the aforesaid method is implemented by means of the following steps:

- measuring the extent of the characteristic deformations of the casing profile of at least one tyre fitted on the vehicle, at a given inflation pressure;

- comparing the values of these characteristic deformations with stored values representing the behaviour of the tyre in the measured state of deformation; and

- generating a signal for acting on at least one device regulating at least one mechanism for controlling the behaviour, including attitude, of the said vehicle in motion, corresponding to the action to be taken on the said mechanism to keep the said behaviour of the vehicle within the limits of a predetermined behaviour or to bring it back within these limits.

In a different aspect, the present invention relates to a system for controlling the behaviour of a vehicle in motion, comprising:

- at least one unit for measuring at least one quantity correlated with a force transmitted to the ground by a tyre of the said vehicle;

- a database comprising predetermined values representing the behaviour of the said tyre in relation to the said force; and

- a data processing unit communicating with the said at least one measuring unit, capable of comparing the values of this quantity with the said values of the said database, and of emitting a signal to be used for controlling the behaviour of the vehicle.

The said signal may be an alarm signal or a signal for controlling a mechanism controlling the behaviour, including attitude, of the said vehicle to keep the said behaviour of the vehicle within the limits of a

predetermined behaviour or to bring it back within these limits.

Preferably, the said signal acts on a device regulating
5 the said control mechanism.

Preferably, the measuring unit is capable of measuring the rotation velocity of the tyre and/or its inflation pressure.
10

In a preferred embodiment of the system according to the invention, the aforesaid measuring unit comprises at least one sensor inserted into the supporting rim of the tyre and also, if necessary, a reflecting element located
15 on the inner surface of the said tyre.

In a particular aspect of the invention, the quantity measured is the deformation of the casing profile of the tyre in a predetermined direction, preferably selected
20 from the radial direction, the transverse direction and the circumferential direction.

In a further aspect, the present invention relates to a pneumatic wheel for vehicles comprising:
25 - a supporting rim which can be associated with a hub of the vehicle;
- a tyre fitted on the said rim, comprising a casing structure provided with a crown portion extending axially between a pair of axially opposed sidewalls,
30 terminating in beads for joining the said tyre to the corresponding supporting rim, the said casing being provided with at least one reinforcing ply, having terminal flaps engaged with corresponding annular reinforcing structures embedded in the said beads,
35 which forms a toroidal profile of the said casing;
- an emitter of a signal which is to be reflected within the said tyre; and

- a receiver of the said signal for the measurement of a quantity correlated with a force transmitted to the ground by the said tyre.

5   In a preferred embodiment of the wheel, the emitter and the receiver are integrated into a single sensor.

Even more preferably, this wheel comprises at least one unit for transmitting the aforesaid measurement to a data
10   processing unit external to the said wheel.

Further characteristics and advantages of the present invention can be found in greater detail in the following description, with reference to the attached drawings,
15   provided solely for explanatory purposes and without any restrictive intent, which show:

In Fig. 1,   a schematic diagram of a pneumatic wheel;
20   in Fig. 2,   a transverse section through a tyre fitted on its supporting rim under a static load;
             in Fig. 3,   a transverse section through a tyre fitted on its supporting rim in conditions of lateral drift;
25   in Figs. 4a, 4b, a longitudinal section through a tyre fitted on its supporting rim in uniform (Fig. 4a) and braking (Fig. 4b) conditions of motion;
             in Fig. 5,   a transverse section through a tyre fitted on its supporting rim in conditions of lateral
30   drift, showing a system of measuring the deformations according to the invention;
             in Fig. 6,   a longitudinal section through a tyre fitted on its supporting rim in braking conditions, showing a system of measuring the
35   deformations according to the invention;

in Fig. 7, a graph representing the flattening of a
tyre in static conditions as a function of the
vertical force exerted on it;

in Fig. 8, a graph of the lateral force developed by,
5 or exerted on, a tyre in dry and wet road
conditions as a function of the angle of drift;

in Fig. 9, a graph of the longitudinal force
developed by, or exerted on, a tyre in dry and
wet road conditions as a function of the
10 longitudinal creep;

in Fig. 10, the cross section in a radial plane of a
pneumatic wheel, showing the system of
Cartesian coordinates used to plot graphs
corresponding to those in Figures 7, 8 and 9
15 according to the invention;

in Fig. 11, the footprint area of the tyre, modified
to a kidney-bean shape, with the paths of the
bead wires, the mid-line of the tread strip and
a series of radial planes, with the
20 corresponding value of X_2 shown for each of
these;

in Fig. 12, a block diagram of the tyre monitoring and
vehicle control system; and

in Fig. 13, a flow chart of an example of an action
25 taken by the control system.

Figure 1 shows schematically the structure of a wheel
with two springs m1 and m2 fitted in series between the
hub M of the vehicle and the surface G of the ground.
30

The spring m1 represents schematically the casing
structure of the tyre, while the spring m2 represents
schematically the structure of the tread strip, which has
its own specific elasticity, dependent on the visco-
35 elastic characteristics of the mixture and on the
geometrical characteristics of the tread pattern.

The force F applied to the footprint area of the tyre is balanced by an equal and opposite force F applied to the wheel hub. Without knowing the behaviour of m1, it is impossible to know the value of the deformation corresponding to the force acting on m1.

In other words, it is not possible to deduce the deformed configuration of the casing in a unique way from the measurements made on the footprint area. Similarly, it is not possible to determine in a unique way the deformation of the footprint area, which depends on parameters which are frequently unknown, particularly the value of the coefficient of friction between the tyre and the ground. The Applicant has realized that the deformed casing profile, at a given inflation pressure, in itself describes the actual behaviour of the tyre in motion.

Thus it is possible to determine in advance, for each type of tyre and for each value of inflation pressure, the deformations which the tyre undergoes in a triad of Cartesian coordinates, according to the stresses applied to it, in various operating situations, particularly with different values of the coefficient of friction and with different values of the angle of drift.

The comparison between the deformations of the casing profile measured in tyres in use and the predetermined deformations, conveniently organized in a database, can be used to generate appropriate corrective actions on the various devices or systems for controlling the behaviour of the vehicle to which the tyres are fitted, to keep the said behaviour of the vehicle within the limits of a predetermined behaviour, or to bring it back within these limits. This is particularly true if the behaviour of the vehicle to the forces applied to the wheel hubs is known for the vehicle in question.

The aforesaid systems include, for example, variable adjustment systems of the suspension units, an anti-lock braking system (ABS), an engine and traction control system (antiskid), a stability control systems (ESP), an active systems for controlling the motion of suspended weights (ABC) and non-suspended weights, and systems of dynamic regulation of the angles of "camber" and/or toe-in.

The aforesaid database may advantageously be supplied by the tyre manufacturer as a component of a vehicle behaviour control system.

Significant parameters for the purposes of the interpretation of the measurements and the aforesaid comparison of the deformations of the tyre and of the nature and extent of the corrections to be made by means of the aforesaid devices or control systems are the value of the tyre inflation pressure and the velocity or acceleration of each wheel.

For the purposes of the present invention, the aforesaid deformations of the casing profile are defined thus:
- flattening (X_1): the direct deformation along a vertical axis or any axis perpendicular to the road surface;
- lateral displacement or skid or drift (X_2): the direct deformation along the axis of rotation of the tyre; and
- longitudinal creep (X_3): the direct deformation along the circumferential direction, in other words the direction of rolling of the tyre.

The measurements of these deformations are expressed as variations (Δ) of X_1, X_2, X_3 with respect to corresponding values measured on the equilibrium profile of the tyre at a specific inflation pressure.

The comparison with predetermined values of these deformations in relation to measured and controlled forces applied to the tyre, preferably with the additional knowledge of the rotation velocity of each
5   wheel, can be used to act automatically and/or under the control of the vehicle driver, for a single tire of pairs of tyres or all tyres, on the aforesaid control devices or systems, in order to bring the values of the said deformations X_1, X_2, X_3 back within predicted and
10   predetermined limits, to achieve a better behaviour of the vehicle in predetermined, and sometimes critical, situations.

Figure 2 shows by way of example a wheel comprising a
15   tyre 1, of the type conventionally called "tubeless", and a supporting rim 2. This tyre 1 is inflated by means of an inflation valve 3 located, for example, in a known way on the channel of the said rim.

20   The tyre 1 consists of an internally hollow toroidal structure formed by a plurality of components, and primarily of a casing ply 4, made of fabric or metal, having two beads 5 and 5' each formed along an inner circumferential edge of the casing to secure the tyre to
25   the corresponding supporting rim 2. A pair of annular reinforcing cores, called bead wires, 6 and 6', which are circumferentially non-extendible, inserted in the said beads (at least one bead wire per bead as a rule) is also provided.
30

The casing ply includes a supporting structure comprising fabric or metal cords, extending axially from one bead to the other to form a toroidal structure which has each of its edges associated with a corresponding bead wire.
35

In tyres of the type known as radial, the aforesaid cords lie essentially in planes containing the axis of rotation of the tyre.

5 An annular superstructure, known as the belt structure 8, is placed on the crown 7 of this casing, and normally consists of one or more strips of rubberized fabric wound so that they overlap each other and form what is called a "belt pack", and a tread strip 9 of elastomeric material,

10 wound around the belt pack, impressed with a relief pattern for rolling contact of the tyre with the road. Two sidewalls 10 and 10', of elastomeric material, each extending in the radial direction towards the outside from the outer edge of the corresponding bead, are

15 additionally placed on the casing, in lateral axially-opposed positions.

In tyres of the type known as "tubeless", in other words, those not requiring the use of air chambers when in operation, the inner surface of the casing is normally

20 covered with what is known as a "liner", in other words, one or more layers of elastomeric material impermeable to air. Finally, the casing may comprise other known elements such as edges, strips and fillers according to the specific design of the tyre.

25

The forces transmitted by the tyre to the ground in a given situation, static or dynamic, are associated with the deviations of the casing profile in use from the basic inflated profile of the casing.

30

The profile of the casing in use is also described by the term "deformed configuration of the casing", while the basic inflated profile of the casing, in other words, that which the casing has in the tyre fitted on the rim

35 where it is to be used and inflated to its nominal operating pressure, in the absence of a load, is termed, albeit incorrectly, the equilibrium profile.

For the purposes of the present invention, the term
"casing profile" signifies the profile along the neutral
axis of the casing plies in the cross section of the
5   tyre. In particular, the casing profile describes the
deformed configuration of the said tyre under the effect
of the system of forces acting on it.

Figure 2 shows, in particular, the radial distance X_1
10   along the equatorial plane E of the tyre between the
inner surface of the rim 2 and the inner surface of the
tyre in the area of the crown 7. The flattening undergone
by the tyre under load is represented by the decrease of
X_1 with respect to the corresponding value on the
15   equilibrium profile. In the present description, for the
sake of simplicity, X_1 will be defined as the flattening.

This distance is inversely proportional to the load
exerted by the vehicle on the tyre, and depends both on
20   the inflation pressure of the tyre and on the structural
characteristics of the tyre. In static conditions, there
is no dynamic load, but simply the static load (weight)
bearing on the wheel.

25   Figure 3 shows, in particular, for a tyre operating in
drifting conditions, the lateral displacement X_2,
represented by the displacement, within the cross section
of the tyre, in a transverse direction with respect to
the direction of motion, identified in Figures 2 and 3 by
30   the letter O, of a point which lies on the inner surface
of the tyre on the equatorial plane, with respect to a
point which lies on the mid-line plane of the rim.

The displacement X_2 is closely dependent on the
35   structural characteristics of the tyre as a function of
the lateral force exerted on the tyre during cornering.
In this situation, the casing of the tyre undergoes a

deformation in its midline plane, so that the portion of tread in contact with the ground, which has a substantially elliptical configuration during travel in a straight line, takes on what is known as a "kidney bean"

5   configuration which subjects the sidewalls of the tyre to different stresses, with consequent lateral displacement of the centre of gravity of the tyre towards the inner side of the corner around which it is travelling.

10   It should be noted that the deformed casing profile varies with the variation of the radial plane in question, as shown in Figure 11. This reaches a maximum in a certain section of the footprint area, which is a function of the angle of drift of the tyre. Consequently,

15   the corresponding value of X_2 varies over time as a function of the position of the section in which it is measured. This is because different sections along adjacent planes show a different deformation of the casing profile.

20

More specifically, Figure 11 shows the outline k of the footprint area modified into a kidney-bean shape, the paths c_1 and c_2 of the bead wires, the midline mz of the tread strip and a set of radial planes t_1, t_2, t_3, t_n

25   which show the variation of X_2 in the passage from one plane to another.

Figure 4a shows a longitudinal section through a tyre which rolls as shown by the arrow V at uniform velocity,

30   while Figure 4b shows a longitudinal section of the same tyre which rolls as shown by the arrow F during a deceleration due, for example, to braking. Figure 4b shows in detail the longitudinal creep X_3 in the direction of rolling of the tyre, in other words, in the

35   direction corresponding to the motion of the vehicle (identified in Figures 4a and 4b by the letter D), between a point on the inner surface of the tyre and the

corresponding point on the rim in the equatorial plane of the tyre.

It should be noted that the creep X_3 and the displacement X_2 are measurements only of relative displacements between the casing and rim. In drifting, as in braking or acceleration, there are additional factors due to the flexibility of the elastomeric material which forms the tread strip of the tyre and the pattern formed in the said strip. In other words, if the tyre has a tread strip formed with blocks, the creep and transverse displacement of the ground contact surface of the tread strip with respect to the rim also depend on the flexibility of the blocks.

The Applicant has discovered that the variations of the three parameters described above, preferably measured on several occasions for a predetermined period of time, more preferably measured in a time interval of less than a thousandth of a second in each case, combined with the measurement of the inflation pressure of a tyre when in use and preferably also the rotation velocity of the tyre, are sufficient to determine the behaviour of each tyre in motion fitted on the vehicle, and to predict the behaviour of the said vehicle in the absence of actions taken to modify its behaviour, including attitude.

This is because, when X_1 is measured and the inflation pressure and rotation velocity of the tyre are known, it is possible to determine the dynamic load ("vertical force") to which a tyre is subjected when in motion. The load may, for example, have a direct effect on the vehicle's roadhandling, since an incorrect distribution of the load over the four wheels may cause a loss of adhesion in one or more wheels, for example in cornering or braking, on a dry or wet road.

The knowledge of this parameter is of fundamental importance for the control of the vehicle's behaviour, since, in the aforesaid operating conditions, there is a transfer of the load between the axles and/or between the tyres of a single axle.

The measurement of X_2 provides an indication of the behaviour of the tyre in cornering. The lateral force exerted by each tyre on the ground is directly dependent on its deformed configuration, in other words on X_2. When the angle of drift exceeds a critical value, the tyre starts to skid laterally, with a decrease of the lateral force exchanged with the ground, as shown in Figure 8. This skid can be detected from the decrease of X_2.

The measurement of X_3 provides an indication of the possibility of the tyre's skidding or spinning on the ground in the longitudinal direction. This is because, during braking or acceleration, X_3 increases with the increase of the braking or driving torque which is exerted on the tyre. A decrease of X_3 may signify that the tyre has started to skid or spin in the longitudinal direction on the ground.

This skidding or spinning implies a loss of adhesion, and therefore a smaller force transmitted to the ground, and corresponding modification of the deformed configuration of the casing in the direction of return to the equilibrium profile, with a consequent decrease of X_3.

During braking, this may mean that the tyre in question is no longer providing the correct ground adhesion, thus allowing the vehicle to skid. During acceleration, this decrease of X_3 may signify that one or more of the driving wheels is slipping, causing what is known as the "spinning" of the wheels of the vehicle.

According to another aspect of the present invention, these parameters are measured inside the tyre by means of appropriate sensors. For example, see figure 2, in a preferred embodiment, a sensor/emitter 11 (termed a "sensor" for brevity in the following text) is placed within the supporting rim 2, being inserted in the wall of the said rim along the midline plane.

A passive element, for example, a reflecting element 12, which interacts with the sensor 11 in the determination of X_1, X_2 and X_3, may be inserted inside the tyre, particularly on its inner surface, in contact with the "liner" and on the equatorial plane of the tyre.

This is because the distance X_1 is equal to the distance between the reflecting element 12 and the sensor 11 in the direction of the rolling radius of the tyre, the distance X_2 is equal to the distance between the reflecting element 12 and the sensor 11 in the transverse direction, and the distance X_3 is equal to the distance between the reflecting element 12 and the sensor 11 in the direction D.

To measure these distances, the sensor 11 emits a signal which is reflected by the reflecting element 12 with an intensity varying according to its position with respect to the sensor. The reflection time of the signal can be measured in combination with or as an alternative to the measurement of the intensity. The reflected signal received by the sensor is appropriately encoded according to the angle of reflection and/or the differences of intensity and/or of reflection time from predetermined values, in such a way as to determine the value of X_1, X_2 and X_3.

In the embodiment described above, the sensor comprises both the emitting element and the receiving element of the reflected signal. It is to be understood that the two

functions can be carried out by two independent elements separated from each other, or by a single element which combines them, according to the specific technology used.

5   A different method of measuring X_2 is, for example, that defined as optical triangulation. In other words, the sensor emits (Figure 5) a pair of signals s_1 and s_2 in a symmetrical direction with respect to the equatorial plane E towards each of the two sidewalls of the tyre.
10   Preferably, the angle of emission α is in the range from 30° to 60° with respect to the equatorial plane. The differences between the signals reflected from the two sidewalls at the same angle of emission can be used to determine the distances between the sensor and the said
15   sidewalls. The said two distances can be used to find the displacement X_2.

Similarly, the same method can be used to measure X_3 by sending a pair of signals s_3 and s_4 which are symmetrical
20   (Figure 6) with respect to a plane containing the axis of rotation, in the direction of rolling of the tyre, one of the signals being sent in a direction coinciding with the direction of advance of the vehicle, and the other in the opposite direction. Preferably the angle of emission β is
25   in the range from 10° to 90°, and more preferably from 15° to 80° with respect to the radial plane R. The differences between the signals reflected from the inner surface of the tyre determine two values of distance which can be used to find the displacement X_3.
30

By way of example, the signal emitted by the sensor 11 may be in the form of sound waves, for example, ultrasound or electromagnetic waves, or, light waves, which are reflected from the reflecting element 12 or
35   from the inner surface of the tyre. Reflection obtained from the inner surface of the tyre, in the absence of reflecting elements added to or formed on it, is

particularly convenient since it does not require modifications to the structure of the tyre or to its manufacturing process or to mounting process. Additionally, the condition of total darkness present within the tyre makes the use of signals of the light type particularly convenient.

The reflected signals can advantageously be corrected as typed within the sensor itself.

It is to be understood that the sensor and the reflecting element described above can be replaced in an equivalent way within the scope of the present invention with other types of sensors and reflecting elements capable of measuring the aforesaid parameters.

The sensor may also comprise a plurality of emitters placed circumferentially, preferably in positions equidistant from each other, in such a way as to record each X_1, X_2 and X_3 several times during the rotation of the wheel.

According to a different aspect of the present invention, the sensor may, instead of measuring the distance between two points, carry out an integration of different measurements between adjacent points, thus reconstructing the shape of an extended portion of the inner surface of the tyre.

The sensor or the system for measuring the deformed profile of the tyre preferably also comprises a pressure gauge and/or a velocity and/or acceleration meter.

In a preferred embodiment, the sensor 11 also comprises a device 13 for measuring the angular velocity of the wheel, located, for example, on the hub of the wheel, this device receiving a pulse, electrical or magnetic for

example, on each complete rotation of the wheel. It is thus possible to count the rotations of the wheel within the unit of time and therefore to measure the angular velocity. This information can be deduced, in the absence
5 of the device 13, from the analysis and processing of a signal emitted and recorded by the sensor 11, by the generation of a signal correlated with the said angular velocity.

10 Within the wheel, and preferably within the casing of the sensor, there is a transmitter capable of sending the data on all the measured characteristic parameters to a receiver connected to a processing unit which is preferably located on the vehicle.
15

In a preferred embodiment, this transmitter comprises an electronic circuit, supplied from a battery or in any other convenient way, which transmits the data relating to the said parameters by means of electromagnetic waves,
20 preferably at short-wave radio frequency, in a frequency range preferably from 100 kHz to 1000 MHz, and even more preferably in digital form.

This transmitter, installed within each wheel of the
25 vehicle, may advantageously comprise both the electronic circuit and the power supply.
Alternatively, according to the invention, the transmitter can be supplied in an intermittent way, for example, by inductive coupling with a fixed power source
30 on the vehicle. To reduce the dimensions to a minimum, the transmitter preferably uses, in a known way, the SMD (Surface Mounting Device) technology of mounting the components, while in order to reduce power consumption to a minimum, electronic components of the CMOS
35 (Complementary Metal-Oxide Semiconductor) type are preferably used.

Typically, this transmitter also comprises a microcontroller which is responsible for the function of controlling the transmitter according to a programmed logic stored within it. The microcontroller processes the
5 received data and sends it to a transmitter circuit which in turn transmits them, by means of an antenna, for example.

The transmitter circuit is, for example, a circuit which
10 is frequency stabilized by means of a SAW (Surface Acoustic Wave) resonator at the frequency of 433.92 MHz. It is connected directly to the power source (battery, inductively charged capacitor, etc.) in such a way that the maximum available voltage can be used. It is capable
15 of supplying a power of approximately 4 mW, with modulation of the ASK (Amplitude Shift Key) type.

According to a further aspect of the present invention,
20 the individual values of the three parameters X_1, X_2, X_3 measured in a specific operating condition are compared with data on the behaviour of the tyre stored in the processor fitted on the vehicle, these data being available for each tyre and for a set of values of
25 inflation pressures and operating conditions of the tyre, having been obtained, for example, from measuring machines in laboratory tests. These data identify the characteristic functions which relate the deformation of the casing structure of the tyre to the force applied, in
30 other words, the performance of the tyre with reference to the flattening under load, defined here as the vertical performance, to the transverse displacement in drifting, defined here as the lateral performance, and to the creeping under torque, defined here as the
35 longitudinal performance of the tyre.

According to this aspect of the invention, the control of the behaviour of a vehicle fitted with pneumatic wheels includes the steps of providing tyre performance data, measuring tyre behaviour data by means of signals emitted
5   within the wheels, comparing the said data with each other, and activating control devices of the vehicle according to the result of the said comparison.

Figures 7, 8 and 9 show some examples of performance,
10   obtained in the laboratory by subjecting a tyre, inflated at its nominal operating pressure and placed on a flat belt moved at a speed of 30 kilometres per hour, in both dry and wet conditions, to the corresponding system of forces, in other words the vertical force, lateral force,
15   and longitudinal force.

In particular, Figure 7 shows a curve of the said vertical performance, which relates what is known as the vertical flattening of the tyre to the vertical force
20   exerted on it, at the specific pressure value of 2.2 bars.

This curve can be directly related to the dynamic load acting on the tyre in motion, since, when X_1 and the
25   value of the inflation pressure are known, it can be used to find the value of the aforesaid load, which is inversely proportional to the distance X_1 in Figure 2.

Figure 8 shows two curves of lateral performance, which
30   relate the angle of drift of the tyre to the lateral force which the tyre develops during cornering, for dry and wet road conditions.

The curves shown in Fig. 8 relate to a certain value of
35   vertical load and inflation pressure: other similar curves can be plotted for different values of pressure and different vertical loads.

In these graphs, the distance X_2 is correlated with the applied lateral force, since when the lateral force increases the distance X_2 increases correspondingly.

The graph shows, in a typical way, a first rising portion in which the lateral force increases considerably with an increase in the angle of drift, and a second portion in which the lateral force no longer rises, in spite of the increase in the angle of drift. In some cases, the lateral force actually decreases, particularly on roads with poor adhesion, for example, a wet road.

This signifies that, beyond a certain limit, even if the driver increases the steering angle of the wheels, and consequently the angle of drift of the vehicle, the lateral force no longer increases. Consequently the friction of the tyre on the ground is not increased, thus producing, for the tyres fitted on the front axle, the situation commonly called "understeering".

The Applicant has discovered that, by measuring the distance X_2, which is correlated with the value of the lateral force, and the inflation pressure of the tyre is known, then for a certain vertical load on the wheel known from the measurement of X_1, by means of the graph in Figure 8 it is possible to know when the tyre reaches the maximum possible adhesion on the road surface, even without knowing in advance the coefficient of friction between the tyre and the road surface.

When the data for all the tyres of the vehicle are available, therefore, it is possible to determine whether the roadhandling at the moment in question is optimal or whether the vehicle is about to skid laterally.

Figure 9 shows two curves of longitudinal performance, which relate the longitudinal force exerted on the tyre

to the percentage creep of the tyre with respect to the ground during a phase of acceleration or braking.

In a similar way to Fig. 8, the curves shown represent the force which the tyre may develop in dry and wet conditions respectively. Further curves can be plotted for different values of vertical load and operating pressure of the tyre.

In these curves it can be seen that, in a first portion of the curve, the longitudinal force increases progressively to a maximum value as the creep increases. After this value, the creep increases without a further increase in the longitudinal force. On the contrary, the applied force decreases. This signifies that beyond this value the tyre can no longer be sure of holding the road and starts to skid or spin.

The measured distance X_3 can be related to the creep, since the deformability of the casing structure of the tyre allows torsion of the crown of the tyre about the axis of rotation. When the maximum torsion has been exceeded, the tyre starts to skid or spin on the ground. Consequently, in conditions of sharp acceleration and during hard braking, when the torsion is maximum, X_3 will tend to increase until the tyre spins or skids on the ground. From this instant onwards, the value of X_3 will start to fall sharply, indicating that the tyre is spinning or skidding.

It is therefore possible to know whether the tyre in question is close to spinning or skidding, by monitoring the value of X_3 in acceleration and braking for a certain period of time, and comparing it with the corresponding data on longitudinal performance. In particular, if a creep of the order of 5% or less is found by monitoring

X_3, this confirms that the tyre is operating with a good degree of longitudinal adhesion.

According to the invention, the determination of the three parameters X_1, X_2, X_3 and their comparison with the corresponding performance data not only provides an indication of the state of stress of each tyre in a given operating situation, but also makes it possible to predict the variation of its behaviour in the said operating situation. It thus becomes possible to act on the vehicle driving and/or control system to optimize the vehicle's behaviour.

Additionally, according to the invention, the processing unit is capable of controlling all the devices which determine the correct motion of the vehicle, particularly the devices for regulating the mechanisms controlling the behaviour, including attitude of the said vehicle. These devices (Figure 12) include, for example, a controller of the anti-lock braking system (ABS) 22, a suspension adjustment controller 23, a controller for correcting the inflation pressure of the tyres 24, and a vehicle stability controller (ESP, "Electronic Stability Program", system) (not shown in the figure).

The processing unit is also capable of controlling the fuel supply controller, for example the electronic injection in vehicles in which this is present, in such a way as to act on the power supplied by the engine and transmitted to the driving wheels.

In a preferred embodiment of the invention, the monitoring and control system described above operates in the following way:

For each tyre fitted on the vehicle, the sensor 11 measures for each rotation, or several times within a

single rotation, the aforesaid parameters X_1, X_2 and X_3, and sends them, by means of the transmitter 61 and the receiver 21, to the processing unit 20. The said transmitter also sends to the processing unit the value

5 of pressure **p** and the rotation velocity **g** of each individual tyre. The transmitter transmits these data in a predetermined format such that they can easily be decoded by the receiver 21.

10 The processing unit 20 has available in the store 63 the encoding database of each tyre whose data are represented, for example, by the curves in Figures 7, 8 and 9.

15 Whenever the parameters are received, this unit can compare the measured parameters with the corresponding values contained in the database.

For each tyre, therefore, the parameters X_1, X_2 and X_3 are
20 compared continuously with these curves to verify that the condition of motion of the vehicle is optimal. If one or more of the parameters deviates by a predetermined amount from the optimal value, the processing unit can generate an alarm signal visible to the user by means of
25 a display 27 located, for example, on the dashboard of the vehicle. Advantageously, an arrangement can be made to generate a typical signal for each anomalous event occurring. For example, the alarm signal which identifies the lateral skid in cornering may be different from the
30 alarm signal which identifies the condition of a deflated tyre.

According to the conditions thus identified and/or the type of alarm signal, the processing unit can act,
35 possibly in an automatic way, on the appropriate controller to correct the behaviour of the vehicle.

Figure 13 shows an example of the way in which the vehicle control system according to the invention can operate.

5   It is assumed that the aim is to control the behaviour of a vehicle with a forward-mounted engine and drive system, provided with an active suspension system and a system for distributing the braking among the four wheels, during a braking operation carried out in conditions of
10   travel in a straight line on dry ground.

In order to facilitate the understanding of the example, the flow chart shown here takes into consideration only the control of the braking, disregarding all other
15   parallel control operations which may be executed for overall control of the vehicle's behaviour.

During braking, some of the load is transferred to the front axle of the vehicle and consequently to the two
20   front tyres. The aforesaid control operation is described only for one tyre of each axle since, in the case of motion in a straight line, it is assumed that the pair of tyres on the same axle behave in an identical way.

25   In the case considered by way of example, the measured distance X_{1a} (flattening of the front tyre) decreases, while the measured distance X_{1p} (flattening of the rear tyre) increases as a result of the said load transfer.

30   The braking also generates a longitudinal creep; the front tyres, subject to a greater load, show an increase in the distance X_{3a} (front axle tyre creep) and the rear tyres show a decrease in the distance X_{3p} (rear axle tyre creep).

35

These measured values are compared with predetermined reference values stored in the aforesaid database and

selected from the database, such as those shown in Figures 7, 8 and 9.

The data contained in the database are, for this type of
5   control, PX_{1a}, PX_{1p}, PX_{3a}, PX_{3p}, where, for the aforesaid road surface conditions, PX_{1a} represents the minimum distance X_1 acceptable for a tyre on the front axle, PX_{1p} represents the maximum distance X_1 acceptable for a tyre on the rear axle, PX_{3a} represents the maximum creep X_3
10   acceptable for a tyre before the start of longitudinal skidding on the front axle, and PX_{3p} represents the minimum creep X_3 acceptable in the condition in which the wheel is in motion.

15   It should be noted that these reference values may be selected in different ways, for example in accordance with a more comfortable driving program (with reference values permitting smaller deformations of the tyre) or a more sporty program (with reference values permitting
20   larger deformations of the tyre).

Figure 13 shows a 'flow chart providing an example of the way in which the control system operates.

25   In this flow chart, the following steps are shown:
     - step A: measurement of the values X_{1a}, X_{3a}, X_{1p} and X_{3p};
     - step T_1: comparison of X_{1a} with the reference value PX_{1a} to determine whether the load on a tyre of the front axle exceeds the maximum permissible reference value;
30   - step T_2: comparison of X_{3a} with the reference value PX_{3a} to determine whether the creep in a tyre of the front axle is greater than the maximum permissible reference value of the creep;
     - step T_3: comparison of X_{1p} with the reference value PX_{1p}
35   to determine whether the load on a tyre of the rear axle is less than the minimum permissible reference value;

- step T_4: comparison of X_{3p} with the reference value PX_{1p} to determine whether the load on a tyre on the rear axle is less than the minimum permissible reference value;

5 - step S_1: action on the processing unit of the active suspension system to cause a stiffening of the front suspension;

- step F_1: action on the processing unit of the system for distributing the braking over the four wheels to

10 provide braking modulation by applying a greater load to the front wheels and correspondingly lightening the load on the rear wheels.

After the acquisition of the data on X_1 and X_3, the

15 comparisons determine whether the system has to intervene to correct the behaviour of the vehicle. The flow chart shows that, if the answer is affirmative, the system determines, in all the comparisons T_1, T_2, T_3 and T_4, a condition of excessive braking action with a tendency to

20 probable loss of adhesion of the wheels and consequent skidding of the vehicle. If at least one of the parameters conforms to the standard, in other words does not exceed the corresponding reference value, the system repeats the data acquisition for another comparison. This

25 condition identifies a different behaviour of the vehicle which might require different action by the processing unit.

In the aforesaid case of an affirmative answer, the

30 system acts on the front suspension (action S_1) and on the braking system (action F_1) until the values measured in the tyres are returned to a condition corresponding to the predetermined behaviour of the vehicle.

A further example of control relates to cornering in

35 extreme conditions. With reference to a car with a forward-mounted engine and drive system, the tyre subject to the greatest load is the front tyre on the outside of

the corner. The processing unit monitors this condition, typically measuring a significant decrease of X_1 and increase of X_2 in the front tyre on the outside of the corner, a moderate increase of X_2 and decrease of X_1 in the rear tyre on the outside of the corner, and a moderate increase of X_2 and X_1 in the rear tyre on the inside of the corner which may sometimes even be lifted off the ground.

A correct action in these conditions is, for example, to stiffen the front suspension on the outside of the corner, in such a way as to limit the rolling of the vehicle body and the characteristic variations of angles of the wheels associated with this, and to distribute the braking so that the brakes are applied more heavily on the tyres which are subject to greater loads (corresponding to a smaller X_1) and therefore have greater friction on the ground.

A vehicle which has a suspension with variable adjustment, particularly active suspension with independent control for each wheel, will make the best use of the invention, since the adjustment of the suspension can be related to each individual tyre.

An example of an active suspension suitable for the purposes of the present invention is described in the previously cited U.S. Patent No. 5,087,072.

Another active suspension control system suitable for the purpose is the system called ABC (Active Body Control) provided on a vehicle made by the motor manufacturer Mercedes. This system requires the use of a suspension whose adjustment is regulated by a hydraulic system controlled by an electronic system. The electronic system is provided with information on the dynamic behaviour of the car by a set of sensors, particularly by

accelerometers located on the vehicle. The action on the suspension is very fast and makes it possible to correct roll which affects the vehicle during cornering.

5   According to the present invention, all these systems, if made capable of receiving information and data directly from the tyre, can correct the attitude of the vehicle by means of the suspension in a much more efficient way than a system which receives the data from accelerometers
10   located on the vehicle.

For example, in respect of the limit of stability, the variation in time of the values measured directly from the tyre can be used to predict precisely the instant at
15   which the tyre will start to spin or skid.

Naturally, other actions may be taken on other control devices, together with or as an ·alternative to the actions on the suspension. For. example, ·a further
20   corrective action may be that of decreasing the speed of· the vehicle by acting on the traction controller which generally applies action to the engine and/or to the braking system.

25   To demonstrate the correlation between the deformations of the tyre casing and the corresponding forces developed by the said tyre, three tables relating the values of the parameters X_1, X_2 and X_3 to the corresponding forces are provided below.
30

These tables show the measurements made on a newly produced P6000 tyre (size 195/65R15) produced by the present Applicant, inflated to a pressure of 2.2 bars, subjected to a set of tests on a laboratory machine
35   (indoor tests). The test machine (road wheel) consists of a cylindrical drum with a diameter of 1700 mm which can be rotated at different speeds. The radially external

surface of the aforesaid drum can be covered with a strip
of suitable material having different characteristics, to
simulate different conditions of the road surface and of
the corresponding coefficient of friction.

5

The values of the parameters X_1, X_2 and X_3 shown in the
table are related to a system of Cartesian coordinates
(x, y, z) having its origin at the centre of rotation of
the tyre, as shown in Figure 10. The sensor 11 (point A)
10   is located on the rim on its midline plane, at the
coordinates (0,0,200), and the point of reflection B is
located in the same radial plane as the sensor 11, on the
equatorial plane of the tyre. Thus the values of the
parameters X_1, X_2 and X_3 shown in the tables correspond to
15   the actual distance of point B from point A in the
appropriate coordinate direction. Table 1 shows the value
of the flattening X_1 with the variation of the vertical
force (load) for the aforesaid tyre in operation at a
speed of 30 km/hr with angles of drift and camber equal
20   to 0°. The tyre was made to roll against the road wheel
by applying a load increasing from 250 kg to 450 kg.

TABLE 1

Load (kg)	X_1, mm
250	89.9
300	87.3
350	84.8
400	82.1
450	79.4

25

The results shown in the table confirm the trend of the
graph in Figure 7 plotted by using a different apparatus,
in other words, the aforesaid flat belt, in the
significant range of values for the vertical load.

30

Table 2 shows the value of X_2 and the lateral force
(drift force) developed by the tyre which travels at a
speed of 30 km/hr with an angle of drift variable between
0° and 6° for successive increments of 0.6°. The test
5 machine is the same as that used for the preceding test,
having the facility for setting an angle of drift for the
tyre, as well as a suitable dynamometer hub for measuring
the force and torque. The test was conducted with a
constant load of 350 kg and with an angle of camber equal
10 to 0°.

TABLE 2

Drift	X_2, mm	drift force (kg)
0	0.4742	6.9
0.6	3.767	55.5
1.2	6.852	101.3
1.8	9.096	135.0
2.4	10.43	154.9
3	11.33	168.7
3.6	11.98	178.6
4.2	12.44	185.6
4.8	12.76	190.4
5.4	12.97	193.8
6	13.12	196.0

The values in the table confirm the values on the graph
in Figure 8 relating to the curve for a dry road.

15

In this table it may be seen that when the angle of drift
increases, the point A is displaced significantly in the
transverse direction to the outside of the corner
(increase of X_2). At the same time, the tyre generates a
20 lateral force which increases as a function of the
deformation of its casing profile.

Table 3 shows the value of the creep X_3 with the
variation of the longitudinal force applied to the axis

of rotation of the aforesaid tyre under a load of
350 kg in operation at a speed of 30 km/hr with angles of
drift and camber equal to 0°.

TABLE 3

Force (kg)	Force (N)	Creep, %	X_3, mm
300	2945	2	2.5
380	3707	3	3.5
420	4121	4	5
460	4464	9	8
450	4420	11	9.8

The values in Table 3 also confirm the values shown in
the graph in Figure 9 in relation to the curve for a dry
road.

The present invention has been described with particular
reference to a four-wheeled vehicle. The invention is
also equally applicable to two-wheeled vehicles and to
any type of vehicle fitted with pneumatic tyres wheels
when the corresponding databases and corresponding
vehicle control functions are provided.

It should be noted that the combination among the
measurements of deformations of the casing along
different axes, in combination with the condition of the
behaviour, including attitude of the vehicle in various
operating situations, for example in drifting, which can
be measured by suitable accelerometers located on the
vehicle, makes it possible to calculate the value of
further parameters, for example the coefficient of
friction, and consequently to select the predetermined
reference values for the comparison.

According to the present invention, the same tests can be
conducted on tyres in various conditions of wear,
pressure and rotation velocity. In the same way, it is

possible to conduct combined tests in the presence of drift and torque. All of this data can be stored in the aforesaid database on the vehicle and used in the most appropriate conditions.

5

It thus becomes possible to monitor and control multiple events.

For example, it is possible to decide whether to modify
10 the pressure of the tyres by acting on the corresponding controller for correcting the pressure, for example, where it is necessary to travel over a snow-covered stretch of road, in order to increase the traction capability of the tyres.

15

The processing unit may also advantageously communicate with a cartographic database 25 containing data concerning the routes to be travelled and an environmental database 26 into which the geographic
20 location of the vehicle and the climatic conditions of the area in which it is located are input in real time.

It is therefore possible to transmit to the processing unit in real time data on the type of road surface, on
25 the climate, dry or wet conditions, and in general the degree of adhesion of the road surface.

Preferably, according to the invention, the system provides for the automatic calibration of all the sensors
30 of the vehicle to provide what is known as a "zero" condition to which all the various measured quantities are related. This condition is preferably that of the vehicle in conditions of operation at a uniform speed close to 0 km/hr, in the presence of a system of forces
35 just sufficient to overcome the resistance to the movement of the vehicle (kinematic condition).

Even more preferably, this zero-point setting is repeated a number of times during the life of the tyre as the state of wear of the tyre progresses.

A set of resident programs for the desired type of driving can also be provided within the processing unit. For example, the comfortable driving program will prevent cornering at the limit of skid of the tyre, by setting the values of the parameters to be compared with the measured ones in a very restrictive way. A possible sporty driving program would be able to give the driver more independence, by comparing the measured values with broader reference values.

CLAIMS

1. Method for controlling the movement of a vehicle including at least one wheel provided with a tyre, the said method comprising the steps of:
   - determining the deformations of the said tyre by measuring them by means of the reflection of a signal emitted inside the wheel;
   - providing a database containing values of deformation of the tyre which correspond to a predetermined behaviour of the wheel;
   - comparing the said measured deformations with the said predetermined values of deformation;
   - emitting a signal dependent on the result of the said comparison, to be used for controlling the behaviour of the vehicle.

2. Method for controlling a vehicle running on pneumatic wheels, which includes the steps of:
   - providing data on the performance of the tyre;
   - obtaining data on the behaviour of the tyre by means of signals emitted within the wheels;
   - comparing the said data with each other and activating control devices of the vehicle in accordance with the result of this comparison.

3. Method for controlling the behaviour of a vehicle in motion, comprising the following steps:
   - measuring the extent of the characteristic deformations of the casing profile of at least one tyre fitted on the vehicle, at a given inflation pressure,
   - comparing the values of these characteristic deformations with stored values representing the behaviour of the tyre in the measured state of deformation,
   - generating a signal for acting on at least one device regulating at least one mechanism for controlling the attitude of the said vehicle in

motion, corresponding to the action to be taken on the said mechanism to keep the said behaviour of the vehicle within the limits of a predetermined behaviour or to bring it back within these limits.

5   4.   System for controlling the behaviour of a vehicle in motion, comprising:

- at least one unit for measuring at least one quantity correlated with a force transmitted to the ground by a tyre of the said vehicle,

10   - a database comprising predetermined values representing the behaviour of the said tyre in relation to the said force,

- a data processing unit communicating with the said at least one measuring unit, capable of comparing

15   the values of this quantity with the said values of the said database, and of emitting a signal to be used for controlling the behaviour of the vehicle.

5.   System according to Claim 4, characterized in that the said signal is an alarm signal.

20   6.   System according to Claim 4, characterized in that the said signal is a signal for controlling a mechanism controlling the attitude of the said vehicle to keep the said behaviour of the vehicle within the limits of a predetermined behaviour or

25   to bring it back within these limits.

7.   System according to Claim 6, characterized in that the said signal acts on a device regulating the said control mechanism.

8.   System according to Claim 4, characterized in that

30   the said measuring unit is capable of measuring the rotation velocity of the said tyre.

9.   System according to Claim 4, characterized in that the said measuring unit is capable of measuring the inflation pressure of the said tyre.

35   10.   System according to Claim 4, characterized in that the said measuring unit comprises at least one

sensor (11) inserted into the supporting rim (2) of the said tyre.

11. System according to Claim 10, characterized in that the said measuring unit comprises a reflecting element (12) located on the inner surface of the said tyre.

12. System according to Claim 4, characterized in that the said quantity is the deformation of the casing profile of the tyre in a predetermined direction.

13. System according to Claim 12, characterized in that the said measuring unit measures the said deformation of the casing profile in at least one direction selected from the radial direction, the transverse direction and the circumferential direction.

14. System according to Claim 13, characterized in that the said deformation in the radial direction is correlated with the vertical force developed by the said tyre at a given inflation pressure.

15. System according to Claim 13, characterized in that the said deformation in the transverse direction is correlated with the lateral force developed by the said tyre at a given inflation pressure.

16. System according to Claim 13, characterized in that the said deformation in the circumferential direction is correlated with the longitudinal force developed by the said tyre at a given inflation pressure.

17. Pneumatic wheel for vehicles comprising:
    - a supporting rim (2) which can be associated with a hub of the said vehicle,
    - a tyre (1) fitted on the said rim, comprising a casing structure (4) provided with a crown portion (7) extending axially between a pair of axially opposed sidewalls (10, 10'), terminating in beads (5, 5') for joining the said tyre to the corresponding supporting rim (2), the said casing

(4) being provided with at least one reinforcing ply having terminal flaps engaged with corresponding annular reinforcing structures embedded in the said beads, which forms a toroidal profile of the said casing,
- an emitter of a signal which is to be reflected within the said tyre,
- a receiver of the said signal for the measurement of a quantity correlated with a force transmitted to the ground by the said tyre.

18. Wheel according to Claim 17, characterized in that the said emitter and the said receiver are integrated into one sensor.

19. Wheel according to Claim 17, characterized in that it comprises at least one unit for transmitting the aforesaid measurement to a data processing unit external to the said wheel.
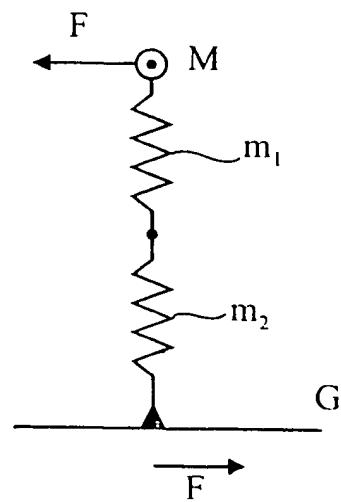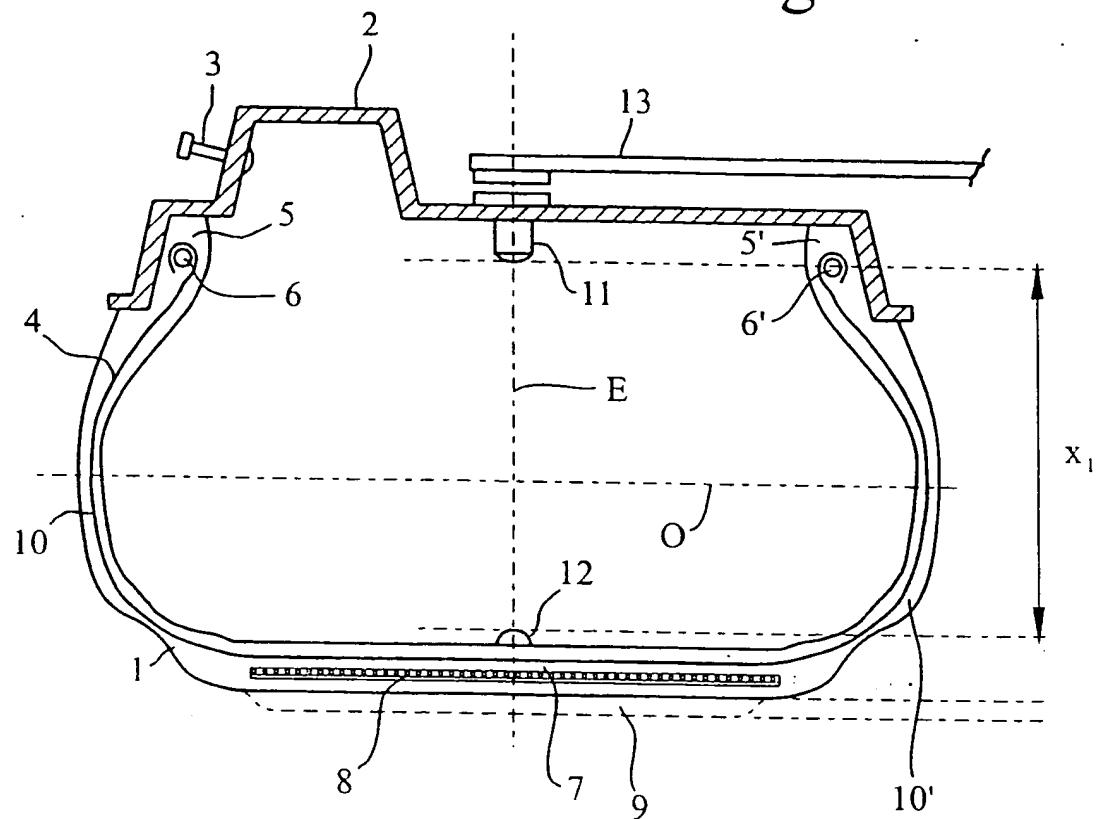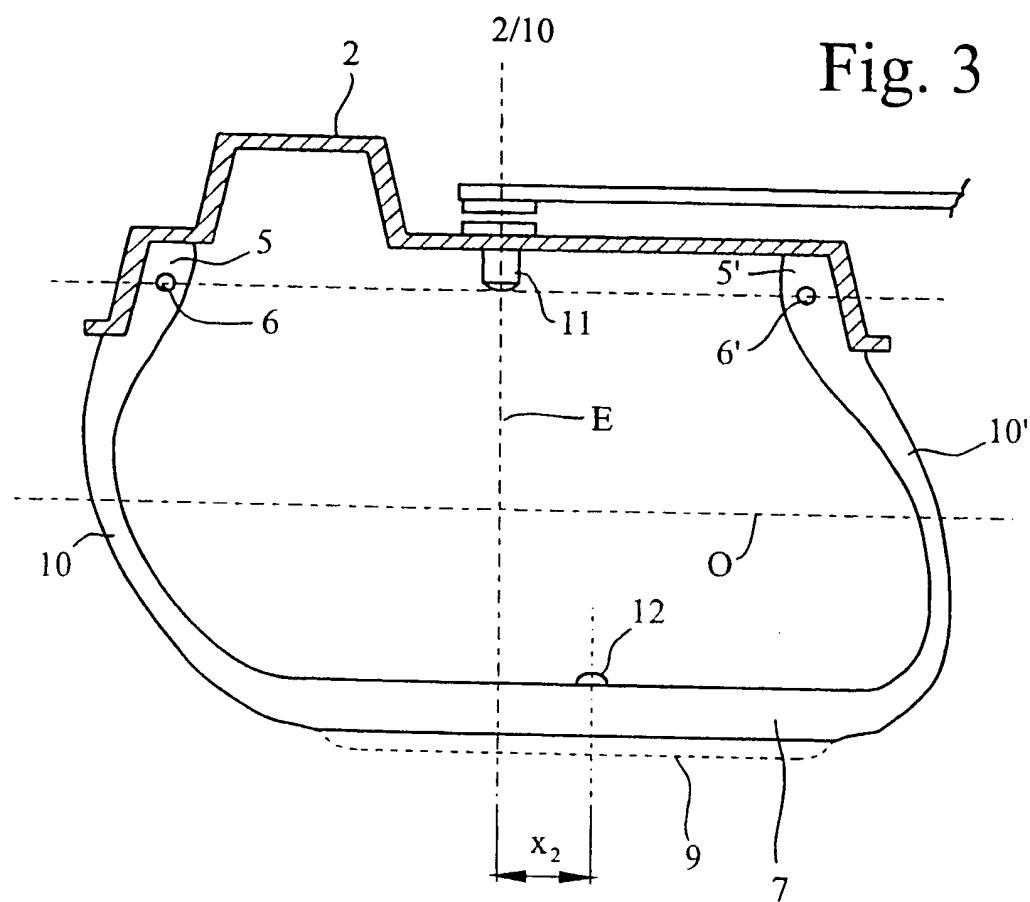
Fig. 2

Fig. 1

Fig. 3

Fig. 11
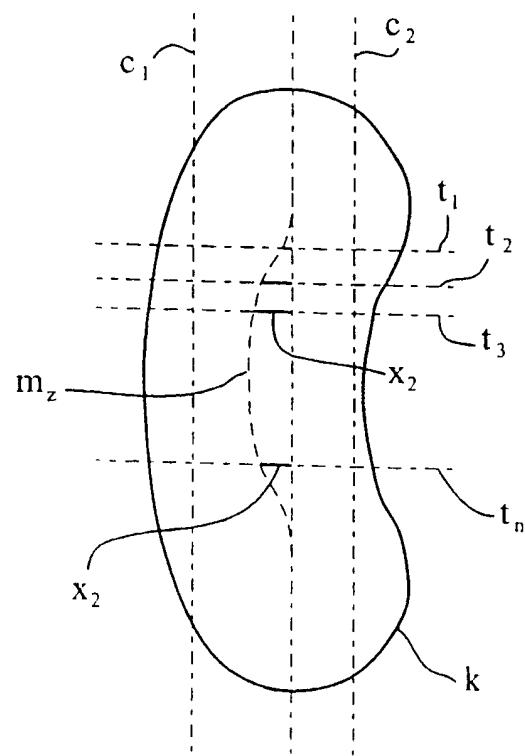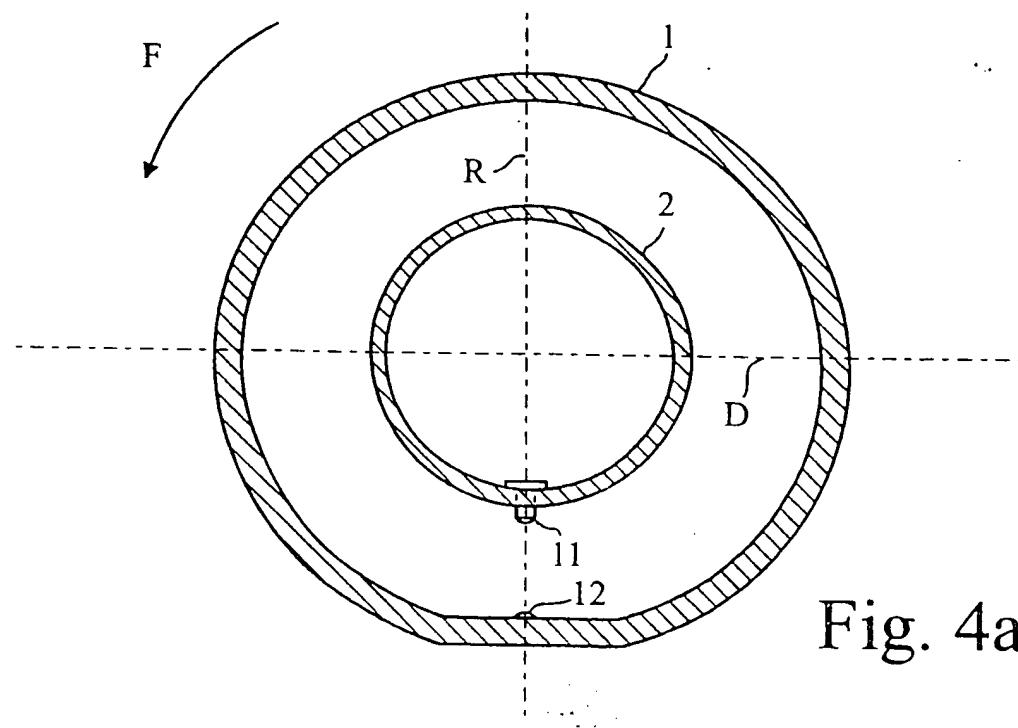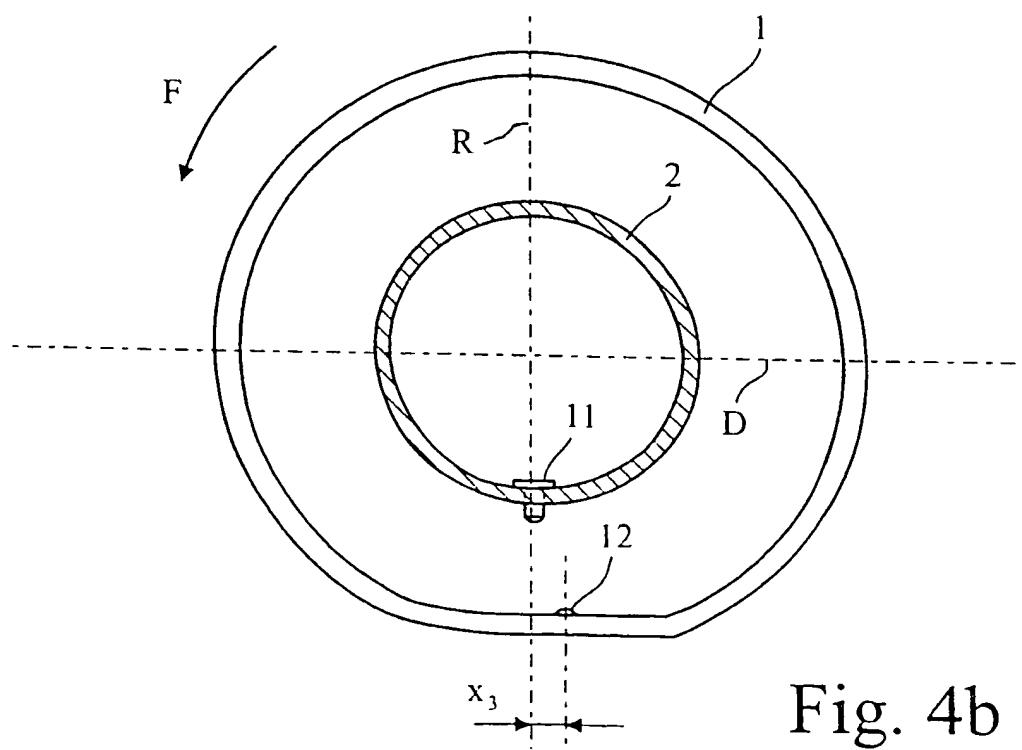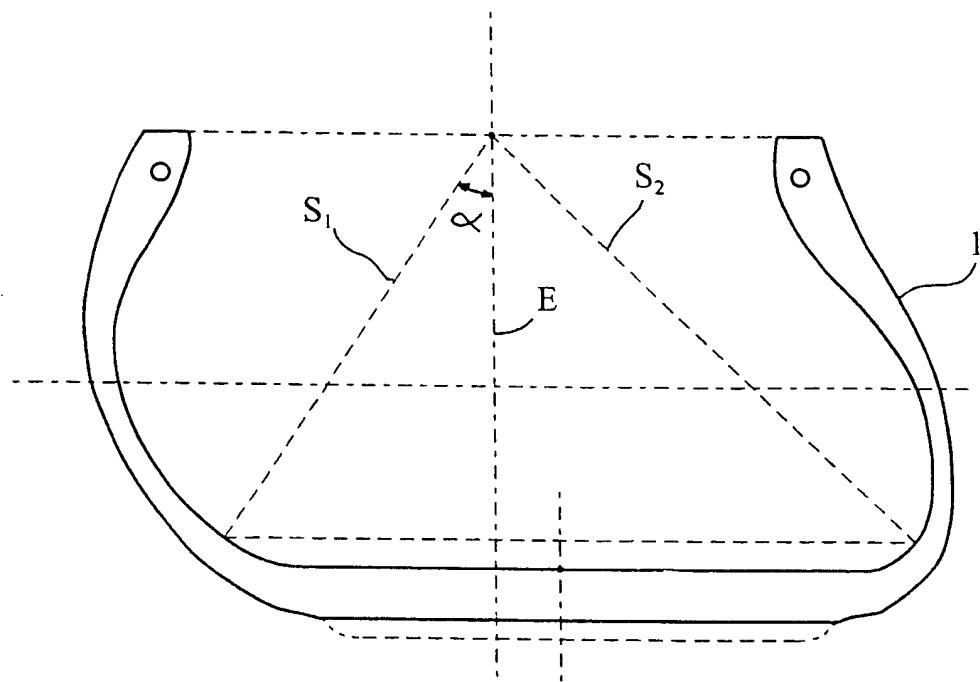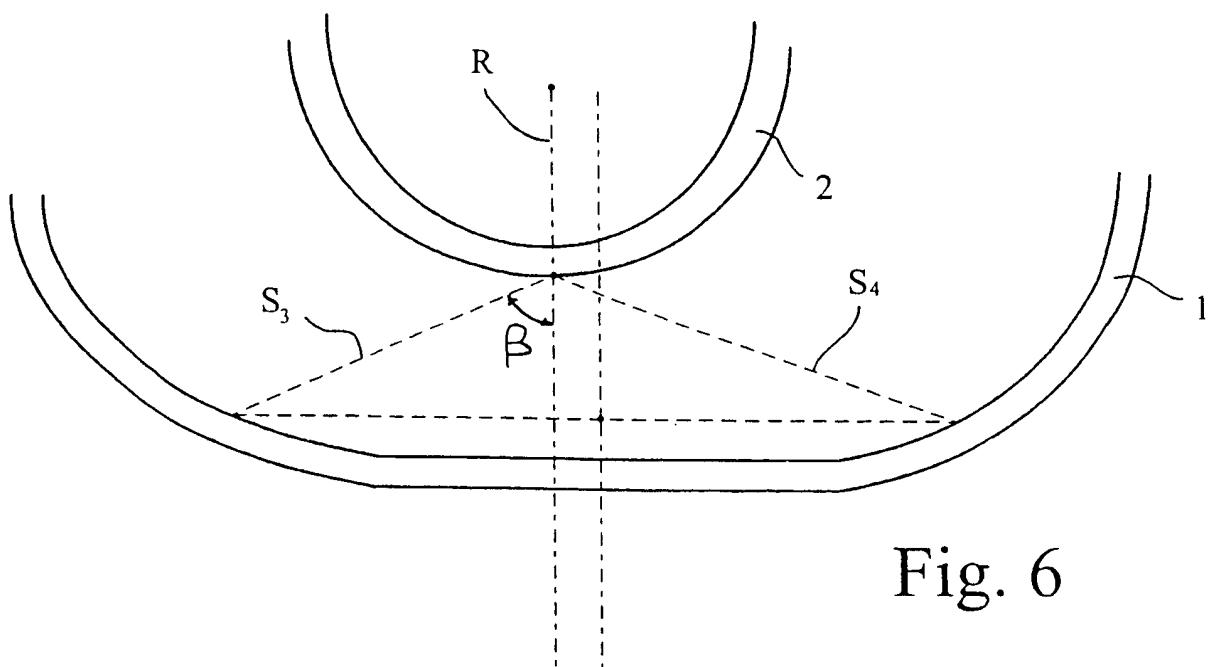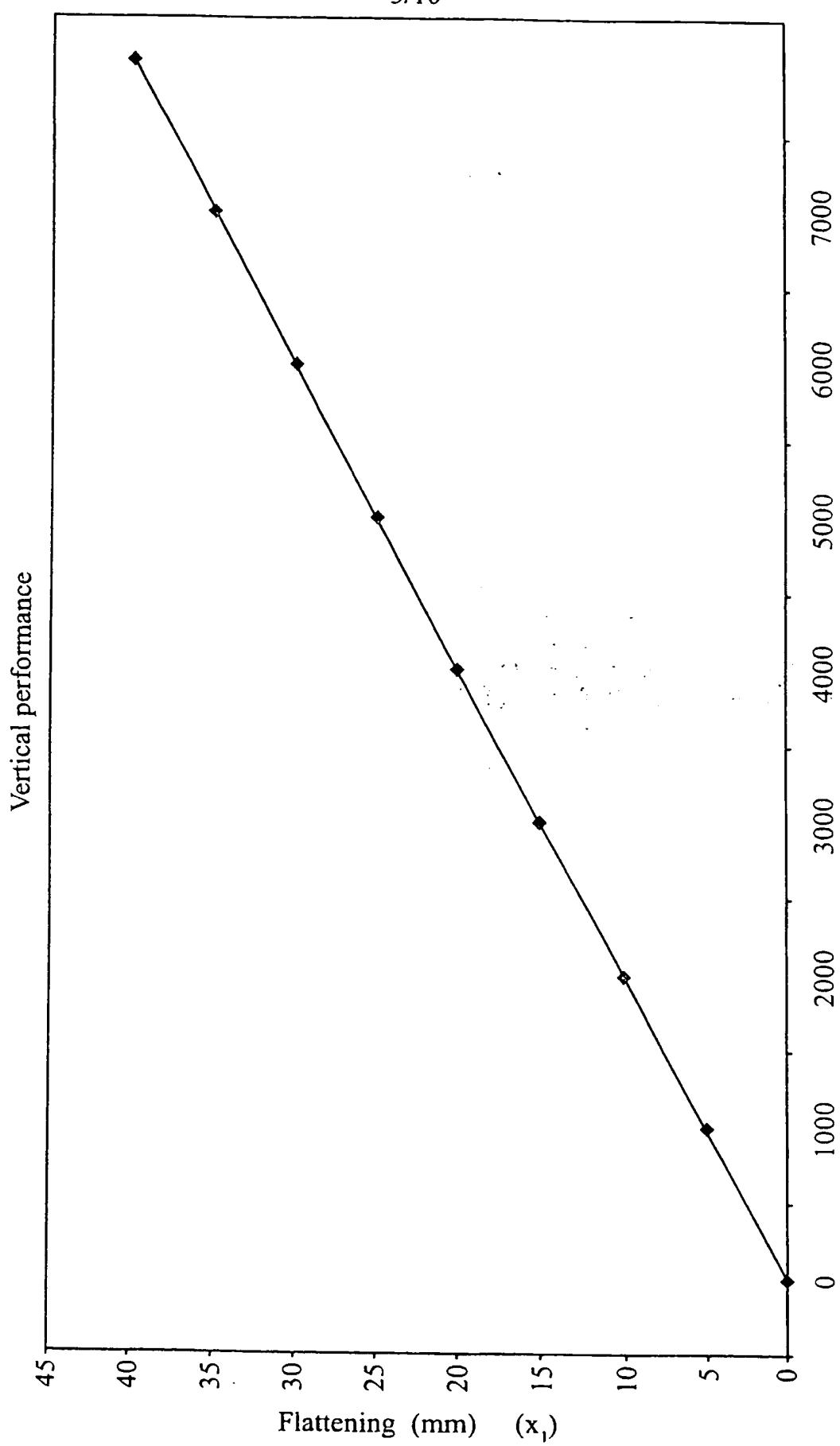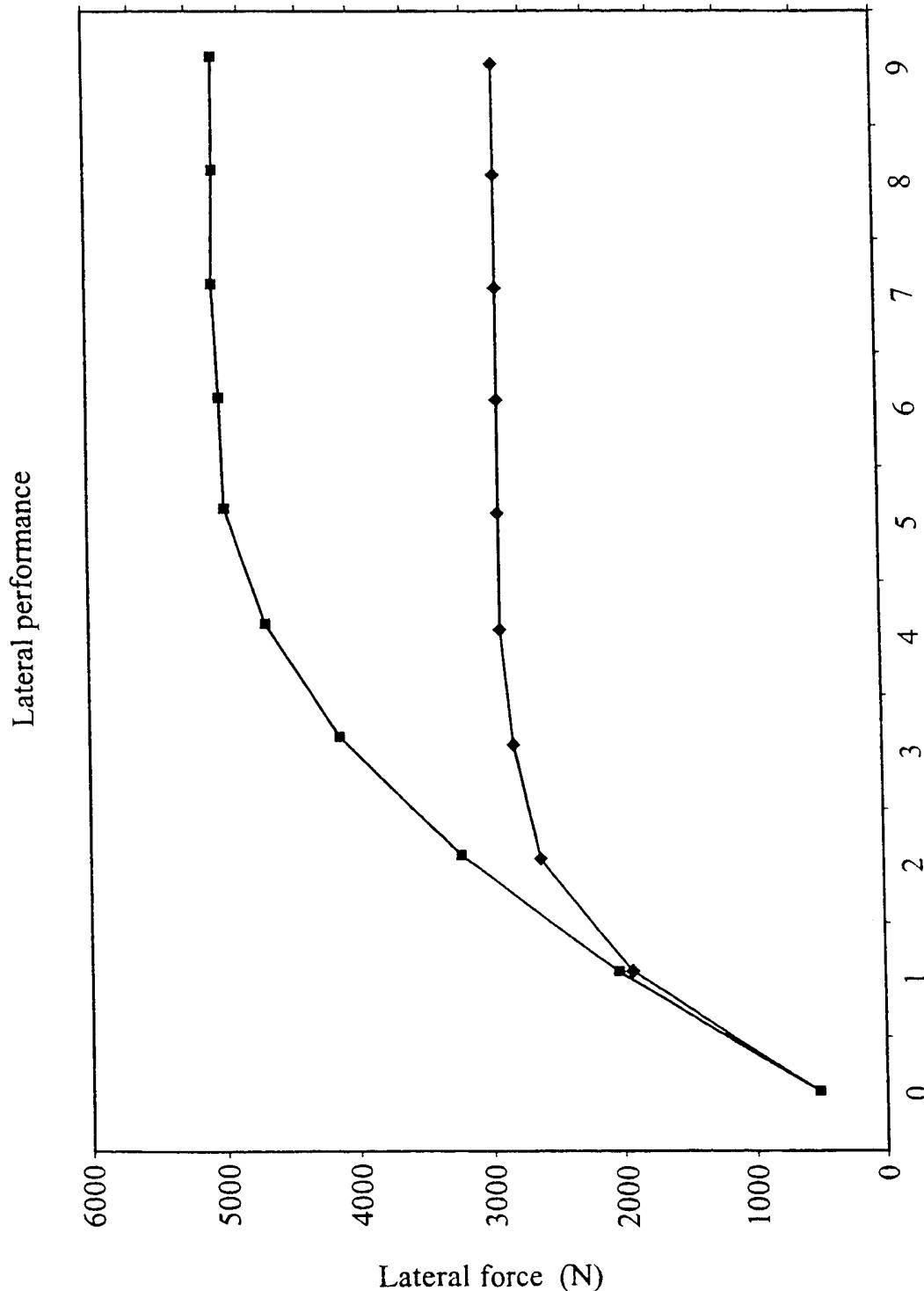
Fig. 4a

Fig. 4b

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Longitudinal performance

Fig. 9

Creep (%)

Longitudinal force (N)

Wet
Dry
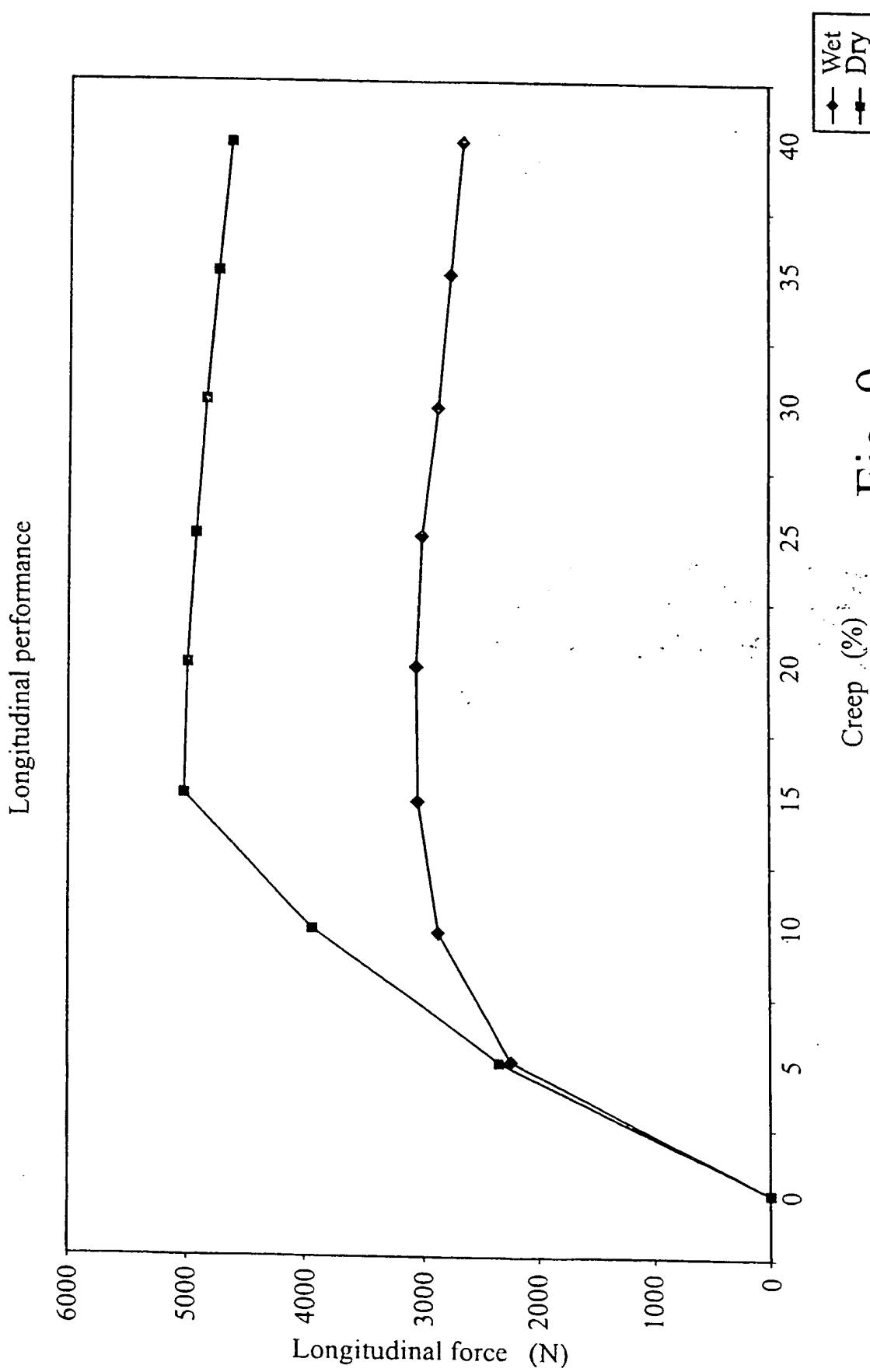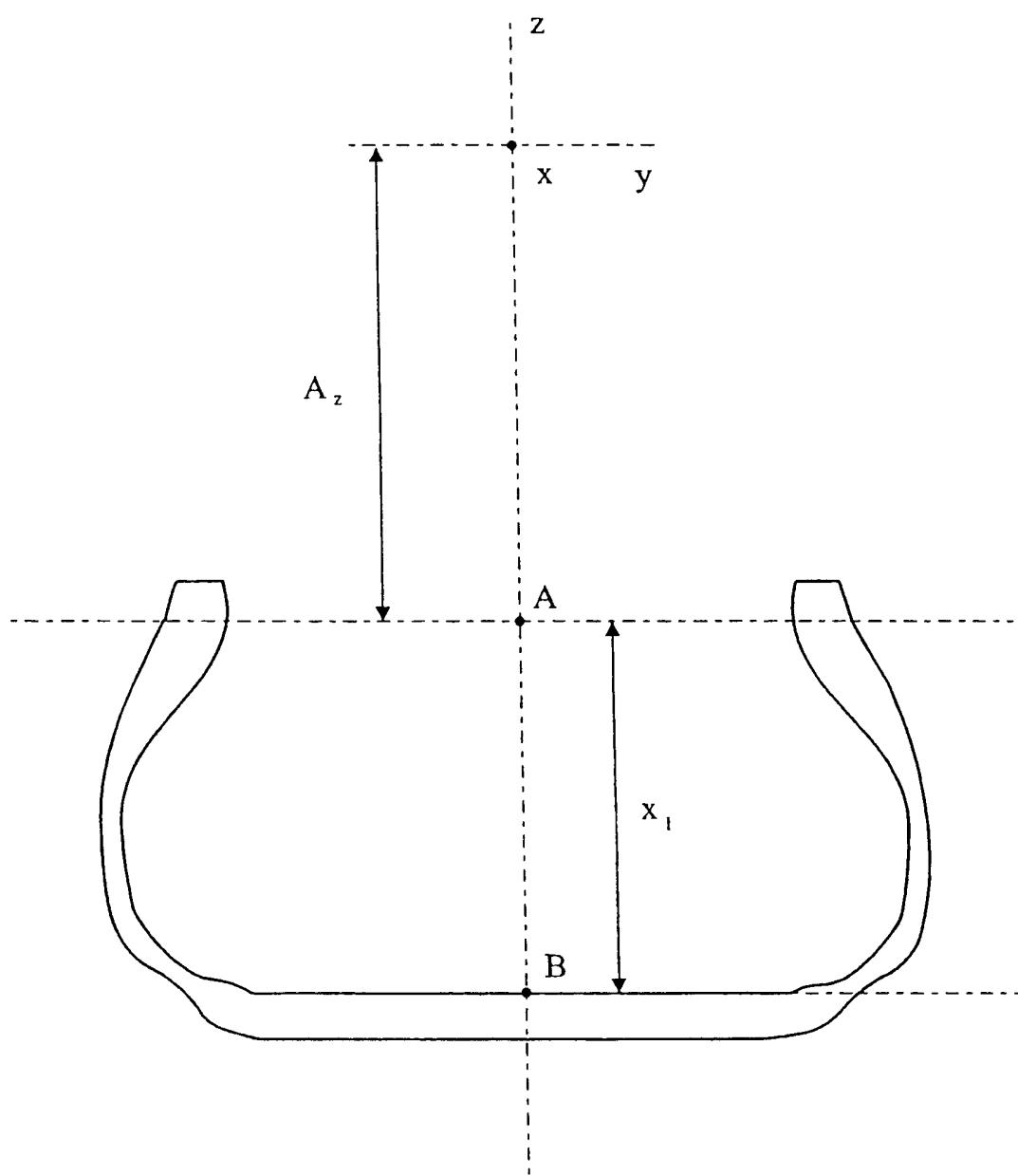
Fig. 10

Fig. 12
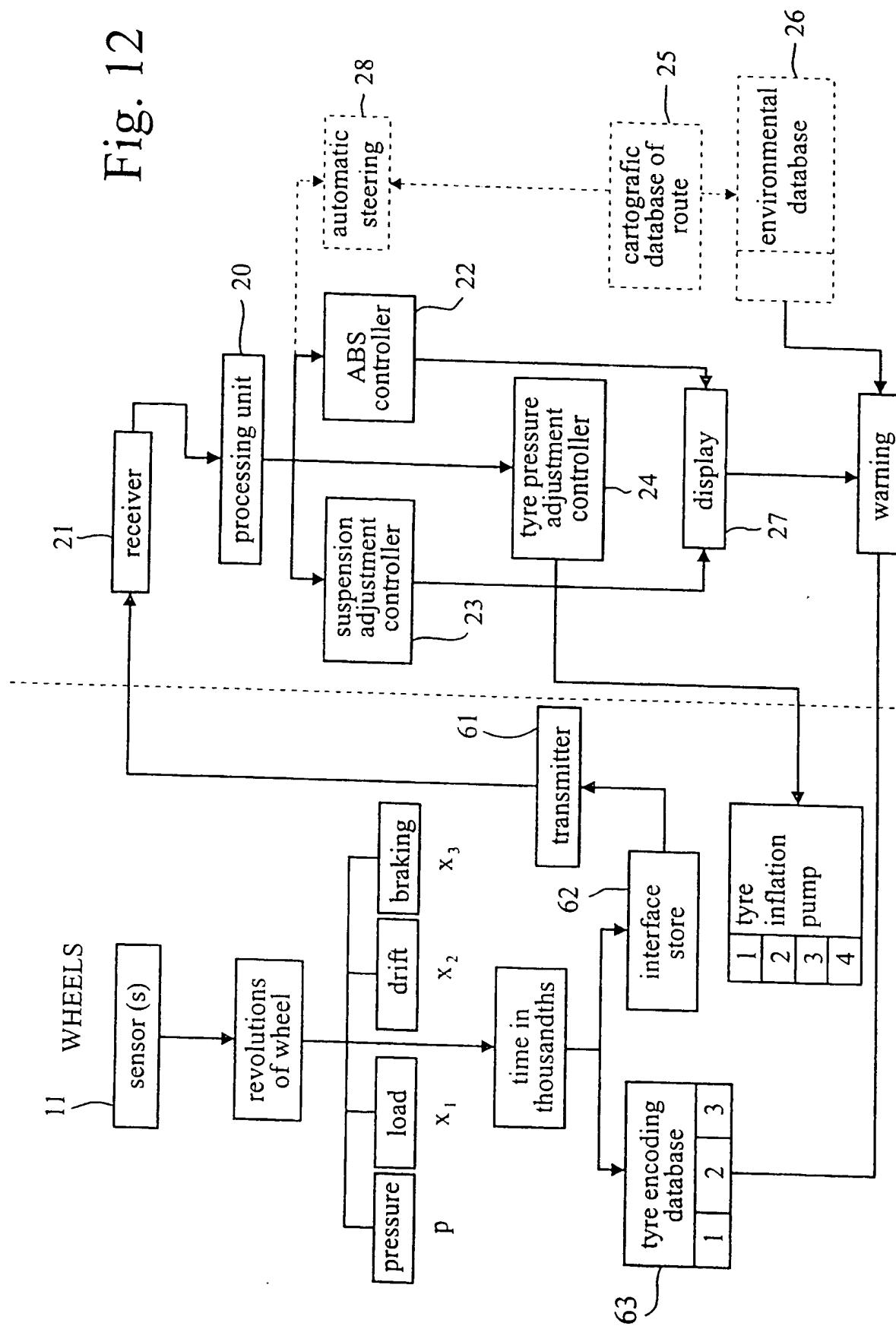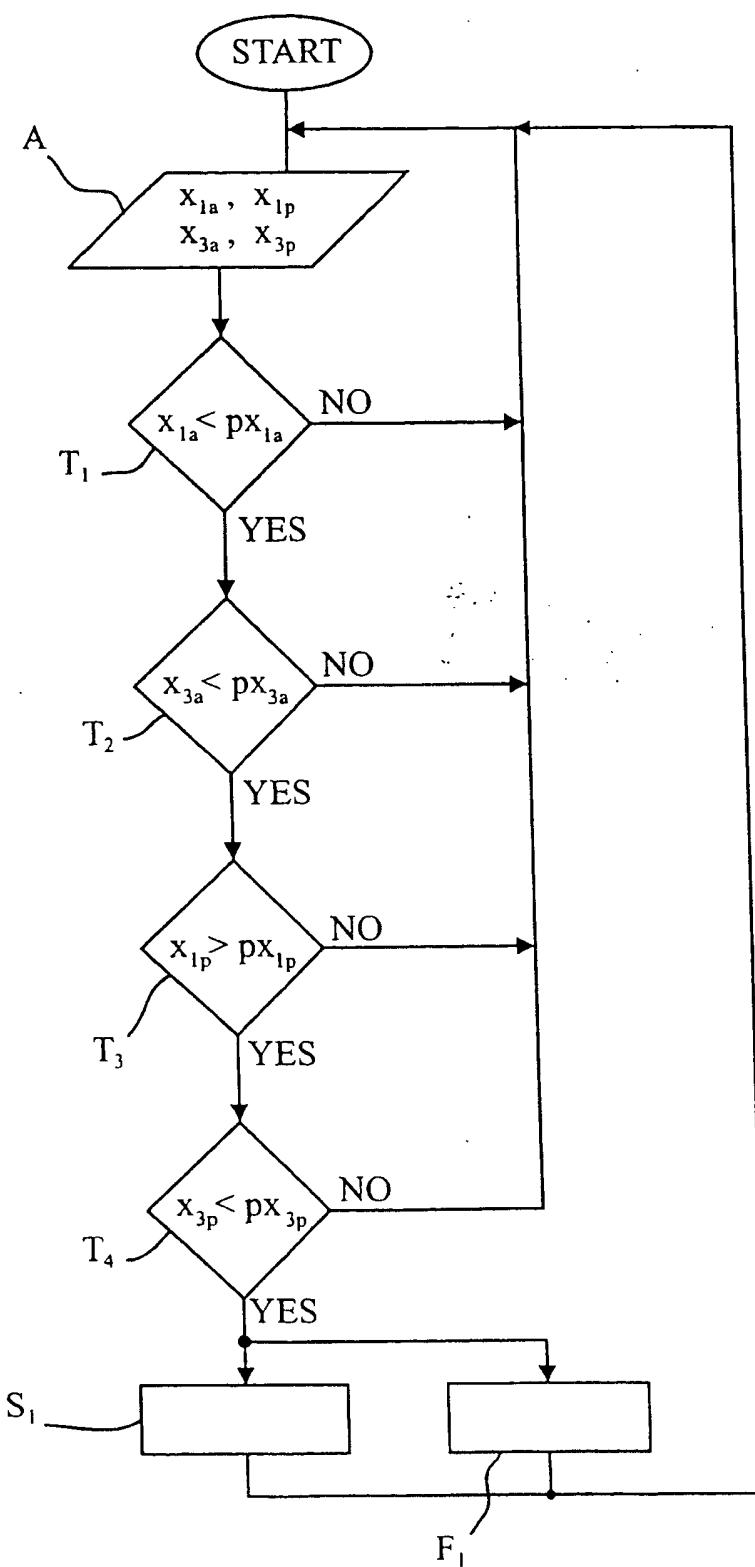
Fig. 13

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   B60C23/06   B60G17/015

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   B60C   B60G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category°	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 247 831 A (FIORAVANTI LEONARDO) 28 September 1993 (1993-09-28) column 1, line 30 -column 7, line 2; figures 1-3	4-8
Y		1-3, 10-12
A		9,14-16
X	DE 39 16 176 A (BAYERISCHE MOTOREN WERKE AG) 22 November 1990 (1990-11-22) column 2, line 31 -column 4, line 15; figure 1	17-19
Y		1-3, 10-12

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 November 2000	24/11/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Smeyers, H

Form PCT/ISA/210 (second sheet) (July 1992)

BEST AVAILABLE COPY

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US 5247831 A	28-09-1993	IT	1223919 B	29-09-1990
		AT	87264 T	15-04-1993
		DE	68905607 D	29-04-1993
		DE	68905607 T	15-07-1993
		WO	9005646 A	31-05-1990
		EP	0444109 A	04-09-1991
		ES	2039098 T	16-08-1993
		JP	2875014 B	24-03-1999
		JP	4503931 T	16-07-1992
DE 3916176 A	22-11-1990	NONE		

THIS PAGE BLANK (USPTO)